

Multiwavelength modeling the SED of very slow novae PU Vul and V723 Cas

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Abstract. Evolution in the spectrum of very slow novae PU Vul and V723 Cas during their transition from the optical maximum to the nebular phase is investigated using the method of disentangling the composite UV/optical spectra. Model SEDs suggested that a transient decrease in the WD luminosity, during the decline from the maximum, was caused by a negative beaming effect, when a neutral disk around the WD was formed. When the disk disappeared, the luminosity increased again to values from the beginning of the outburst (in the case of V723 Cas, at/above the Eddington limit). This suggests the presence of a mechanism maintaining a high energy output for a much longer time than it is predicted by the current theories. Similarity of LCs, but enormous difference of the separation between the components of PU Vul and V723 Cas binaries suggest that the mechanism is basically powered by the accretor.

1. Introduction

Novae represent an observable result of thermonuclear outburst ignited on the surfaces of white dwarfs (WDs). The burning material is accreted from a companion star in binary. In the case of Classical Novae (CNe) the donor star is usually a main-sequence red dwarf transferring matter onto its WD companion via the Roche-lobe overflow. Orbital periods of CN binaries are in order of hours. In the case of Symbiotic Novae (SNe) the thermonuclear runaway phenomena are occurring in binary systems that consist of a WD and a red giant. Orbital periods are in order of years, and the WDs are accreting from the giant's wind. Evolution of the outburst is usually best documented by the optical photometry. It has demonstrated very different profiles of the novae light curves (LCs). To quantify the rates of decline from maximum, the speed classes (from very fast to very slow) were introduced (e.g. Bode & Evans 2008, and references therein).

In this contribution I demonstrate nova evolution, during the transition from the optical maximum to the nebular phase, for two very different types of novae (CN and SN), but with similar LCs. For this purpose I selected the SN PU Vul and CN V723 Cas, whose LCs were classified as very slow. Diversity of types, but basic similarity of their LCs can aid us in better understanding the origin of common properties of their SEDs.

2. Multiwavelength modeling the SED

According to observational properties of novae, their SED in the UV/optical continuum, $F(\lambda)$, can be expressed as a superposition of three basic radiative components, i.e.,

$$F(\lambda) = F_{\text{WD}}(\lambda) + F_{\text{N}}(\lambda) + F_{\text{G}}(\lambda), \quad (1)$$

where $F_{\text{WD}}(\lambda)$ is the flux produced by the WD's pseudophotosphere, $F_{\text{N}}(\lambda)$ is the nebular component of radiation from thermal plasma and $F_{\text{G}}(\lambda)$ represents the contribution from the giant in SNe. For low temperatures, $T_{\text{WD}}^{\text{eff}} \sim 5000 - 15000$ K, an atmospheric model, $\mathcal{F}_{\lambda}(T_{\text{WD}}^{\text{eff}})$, is usually required to fit the optical continuum. For higher temperatures, blackbody radiation can be used to match the UV continuum. From absorption events, acting in the ejecta, we quantify only the attenuation caused by the Rayleigh scattering of the far-UV photons on the neutral atoms of hydrogen. The nebular radiation in the continuum can be approximated by processes of recombination and thermal bremsstrahlung in the hydrogen plasma for *Case B*. Finally, radiation from the giant is represented by an appropriate synthetic spectrum, $\mathcal{F}_{\lambda}(T_{\text{G}}^{\text{eff}})$. Then Eq. (1) can be written in a form,

$$F(\lambda) = \theta_{\text{WD}}^2 \mathcal{F}_{\lambda}(T_{\text{WD}}^{\text{eff}}) e^{-\sigma_{\text{Ray}}(\lambda) N_{\text{H}}} + k_{\text{N}} \varepsilon_{\lambda}(\text{H}, T_{\text{e}}) + \theta_{\text{G}}^2 \mathcal{F}_{\lambda}(T_{\text{G}}^{\text{eff}}), \quad (2)$$

where scalings $\theta_{\text{WD}} = R_{\text{WD}}/d$ and $\theta_{\text{G}} = R_{\text{G}}/d$ represent angular radii of the WD pseudophotosphere and the giant, respectively. The factor k_{N} scales the volume emission coefficient $\varepsilon_{\lambda}(T_{\text{e}})$ of the nebular continuum to observations. Constant T_{e} throughout the nebula is assumed. N_{H} is the hydrogen column density and $\sigma_{\text{Ray}}(\lambda)$ is the Rayleigh scattering cross-section.

In the SED-fitting analysis, model variables (θ_{WD} , θ_{G} , $T_{\text{WD}}^{\text{eff}}$, $T_{\text{G}}^{\text{eff}}$, N_{H} , k_{N} and T_{e}) are given by the solution of Eq. (2), which corresponds to a minimum of the reduced χ^2 function. Atmospheric models for $T_{\text{WD}}^{\text{eff}} = 5000\text{--}15000$ K were taken from Munari & Zwitter (2002) and those for giants from Fluks et al. (1994). More details can be found in Skopal (2005).

3. Results

3.1. Symbiotic nova PU Vul

PU Vul is a well known very slow eclipsing symbiotic nova that exploded at the end of 1977. Its LC shows a ~ 9 -year-lasting flat maximum with some erratic brightenings, followed by a slow decline from the beginning of 1988. It is a binary system comprising an M giant and a WD accreting from the giant's wind on a 13.4-yr orbit (e.g. Belyakina et al. 1982; Kolotilov et al. 1995; Shugarov et al. 2012). Recently, Kato et al. (2012) performed a model of the V-LC consisting of the emission from the outbursting WD, its M-giant companion and the nebulae. Using the model LC, they specified new values of reddening $E_{\text{B-V}} \sim 0.3$ mag and distance $d \sim 4.7$ kpc.

During the flat maximum, an atmospheric model for $T_{\text{WD}}^{\text{eff}} \sim 7000$ K matches well the observed SED. It corresponds to $L_{\text{WD}} \sim 15800 L_{\odot}$ and $R_{\text{WD}} \sim 86 R_{\odot}$. During the decline phase, the two-temperature type of the UV/optical spectrum developed. On 1988 October 10, the measured luminosity decreased to $L_{\text{WD}} \sim 10700 L_{\odot}$ ($T_{\text{WD}}^{\text{BB}} \sim 20000$ K, $R_{\text{WD}} \sim 8.6 R_{\odot}$), a strong nebular radiation with the emission measure $EM \sim 9.6 \times 10^{60} \text{ cm}^{-3}$ was detected, and the far-UV continuum was attenuated by the Rayleigh scattering on $\sim 3.9 \times 10^{22} \text{ cm}^{-2}$ atoms of hydrogen. During quiescent phase, when the signatures of the Rayleigh scattering disappeared, the strong nebula ($EM \sim 9.6 \times 10^{60} \text{ cm}^{-3}$) and the steep slope of the far-UV continuum required $T_{\text{WD}}^{\text{BB}} > 79000$ K, $R_{\text{WD}} < 0.64 R_{\odot}$, resulting in an increase of L_{WD} to $> 14300 L_{\odot}$.

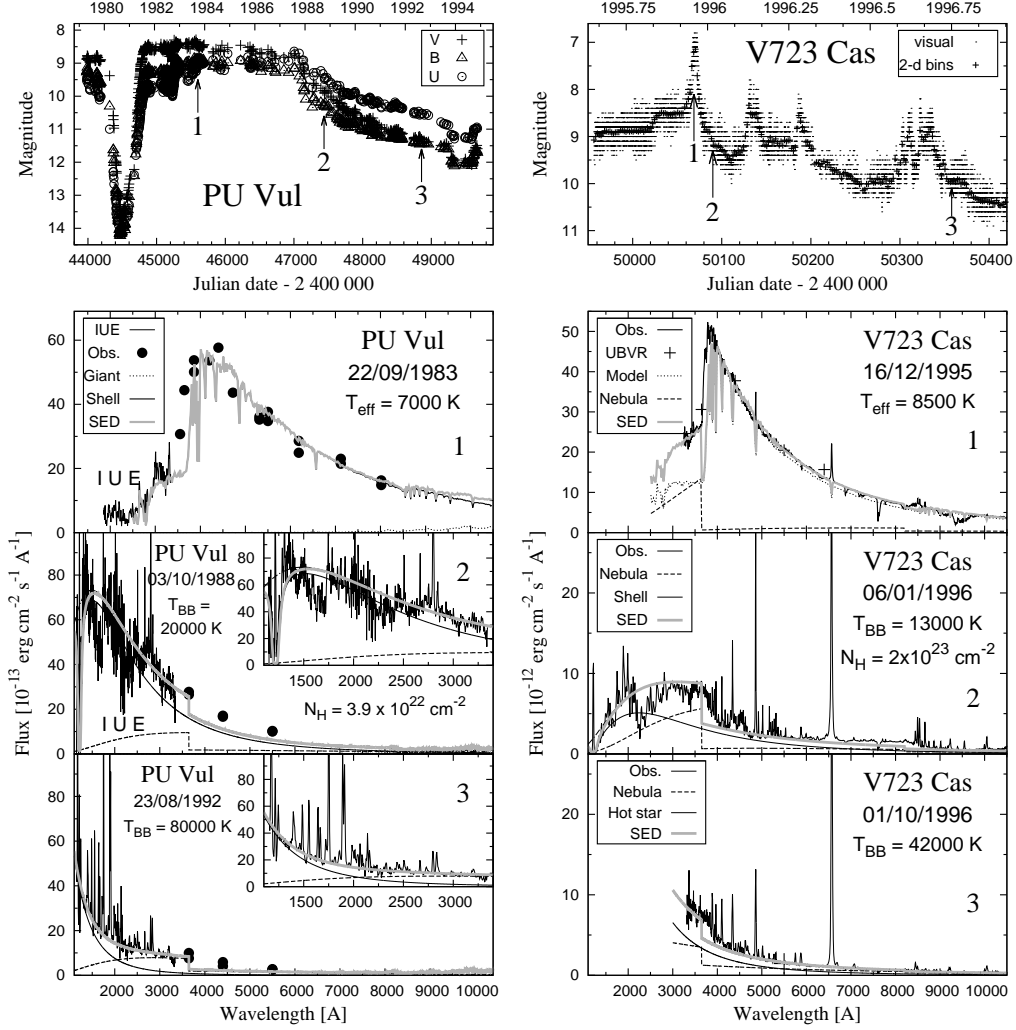


Figure 1. Top panels show the LCs of PU Vul and V723 Cas covering the maximum and following decline. The lower panels display the observed and model SED at dates marked by arrows in LCs. The *HPOL* spectrophotometry (320–1050 nm) of V723 Cas and *IUE* spectra were obtained from archives by MAST.

3.2. Classical nova V723 Cas

V723 Cas was discovered on 1995 August 24. The visual LC of V723 Cas was classified as very slow showing numerous 1 – 2 mag flares on the time-scale of days/weeks (e.g. Munari et al. 1996; Chochol & Pribulla 1997). The authors also noted its similarity to the LC of the SN PU Vul. The orbital period of the V723 Cas binary was determined by Chochol et al. (2000) to 16.6 h. The very slow evolution was also pointed by Ness et al. (2008), who found that V723 Cas was active X-ray source more than 12 years after outburst. Another signature of such behaviour was revealed by Schaefer & Collazzi (2010), who found that the post-eruption LC (> 2003) is brighter by ~ 3 mag than before the eruption.

The model SEDs performed during the same period of the LC-evolution are very similar to those of PU Vul (Fig. 1). During the optical maximum (1995 December 16) the WD's pseudophotosphere was as large as $R_{\text{WD}} \sim 95 R_{\odot}$ and radiated at $T_{\text{WD}}^{\text{eff}} \sim 8500$ K, which corresponds to a super-Eddington luminosity $L_{\text{WD}} \sim 42000 L_{\odot}$ ($d = 3$ kpc, $E_{\text{B-V}} = 0.5$ mag). In addition, a large amount of the nebular radiation ($EM \sim 2.2 \times 10^{61} \text{ cm}^{-3}$) was recognized by the model. At the decline, the two-temperature type of the UV/optical spectrum developed as in the case of PU Vul. On 1996 January 6, the measured luminosity decreased to $L_{\text{WD}} \sim 8700 L_{\odot}$ ($T_{\text{WD}}^{\text{BB}} \sim 13000$ K, $R_{\text{WD}} \sim 14 R_{\odot}$), a very strong nebula with $EM \sim 2.0 \times 10^{61} \text{ cm}^{-3}$ was indicated, and the far-UV continuum was attenuated with the Rayleigh scattering ($N_{\text{H}} \sim 2 \times 10^{23} \text{ cm}^{-2}$). After the 1996 Aug./Sept. flare, the profile of the 320–1050 nm spectrum required significantly hotter stellar source of radiation. The strong nebular emission with $EM \sim 2.6 \times 10^{61} \text{ cm}^{-3}$ required $T_{\text{WD}}^{\text{BB}} > 42000$ K and $R_{\text{WD}} < 4 R_{\odot}$, which means that the luminosity ($> 44000 L_{\odot}$) increased again to/above the Eddington limit. The models are shown in Fig. 1.

4. Concluding remarks

During the optical maxima, the SED of the outbursting WDs was comparable with a 6–9 kK model atmosphere scaled to the luminosity of ~ 16000 and $\sim 42000 L_{\odot}$ for PU Vul and V723 Cas, respectively.

During the decline from maxima, the SED shifted to higher energies having signatures of the neutral disk-like material between the observer and the burning WD. The two-temperature UV spectrum developed. The measured luminosity decreased, because of the undetectable fraction of the WD's radiation emitted to/around the pole directions (a negative beaming effect, see Sect. 5.3.6 of Skopal 2005).

When the neutral material disappeared, the luminosity increased to that from the beginning of outbursts. This suggests the presence of a mechanism maintaining the high energy output for a much longer time than it is predicted by the current theories. Similarity of LCs, but very different separations of the binary components in PU Vul and V723 Cas suggest that the mechanism is basically powered by the accretor.

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